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CONTROLLED AND REVERSIBLE DRAINAGE
PAST, PRESENT, AND FUTURE

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SUMMARY:

Past research, present operational systems, and the future of water table management are summarized as they apply to highly permeable soils of the southeastern United States.

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INTRODUCTION

Controlled and Reversible Drainage (CaRD) is a new name for an old system. Controlled drainage is managing water whereby only that which will hinder crop production is allowed to leave the land. For example, if the rooting depths of plants are 0.6 meters, then the drainage system may allow the water table to be lowered to 0.8 meters. All water below 0.8 meters would remain in the soil profile for future use. Reversible drainage (subirrigation) means placing a positive head of water on the tile or ditch system to maintain the water table at the desired elevation. CaRD systems is a term used to denote that drainage and subirrigation are accomplished with the same system.

Past Research

French scientists, Bordas and Mathieu (1931) reported higher yields from a controlled water table than from other irrigation systems. Some practical aspects of controlled subsurface drainage were considered by Morris (1949) who concluded that in the future all artificial drainage may be controlled drainage.

Fox et al. (1956) presented theoretical criteria for depth and spacing of conduits for subirrigation systems. They suggested that subirrigation required rigid control of the water-table depth. Plant growth can be retarded or stopped completely if the water table is too shallow or too deep. No field data were reported.

Kalisvaart (1958) reported on subirrigation in the Zuiderzee

Poldus in the Netherlands where only agricultural land with low water-holding capacities needed irrigation. In portions of this land, water can be supplied by subirrigation which might be termed--drainage in reverse. He points out that in fields where the subsoil consists of deep and very permeable low terrace sands, "as a rule subirrigation (reversible drainage) will be the most suitable method" for irrigation. He listed five things that may cause drought in portions of the fields under subirrigation: (1) a lack of water supply and low impounded elevation, (2) extremely dry and hot days when evapotranspiration exceeds the ability of the soil to transmit ample water for plant use, (3) excessive lateral losses or seepage away from the canals to prevent controlling the water level, (4) variations in the soil may cause local drying out and crop stress, and (5) defects in the tile system with blockage from silting, iron compounds, and roots which penetrate the lines as principle causes.

In the Unites States most data on subirrigation must be gleaned from drainage research. For example, we find in Table 2.2, pages 34 and 35 of Wesseling (1974), that in 21 of the 35 cases reported, yields decreased when the water table was maintained below certain levels from the surface. Water table depth for maximum yields varied with crops and soil classifications. However, for all soils classified as loams, sandy loam, and loamy fine sands, he showed that there was a minimum water table depth that produced maximum yields. But, for any greater depth to the water tables, yields were reduced.

Tovey (1969), grew alfalfa in lysimeter studies in Nevada with controlled water tables. Water tables were maintained at 60, 122, and 244-cm (2-, 4-, and 8-feet) depths by continuous subsurface drainage.

The results showed that alfalfa can adapt its rooting pattern to either shallow or deep nonfluctuating water tables and produce about the same yield. Irrigation water applied to the soil surface produced little increase in forage yield.

Carter and Floyd (1972) controlled the water table at various depths in small plots of sugarcane in Louisiana. Plots were irrigated by surface and subsurface methods. However, cane yields from irrigated and nonirrigated plots did not differ significantly. In this investigation, the water-holding ("field") capacity of the upper 60 cm (2 ft) of the soil profile was relatively high, 12 cm (4.8 in) which could explain the finding of no difference in yields due to irrigation.

Campbell and Seaborn (1972), Williamson and Carreker (1970), Williamson and Kriz (1970), and Williamson and Van Schilfgaarde (1965) used crop yield and soil aeration criteria for establishing the desired depth of the water table in lysimeter studies.

Rogers and Klute (1972) describe general concepts in terms of nonsaturated flow theory regarding the dynamics between water-table fluctuations in a sand, and changes in soil moisture content above the water table.

Skaggs et al. (1972) and Skaggs (1972) reported that sufficient water can be supplied by subirrigation to meet normal plant needs of certain Coastal Plain soils by controlling the water table with tile lines spaced at 15 m. However, their field studies did not provide appropriate data for determining optimum depth and/or methods of controlling the fluctuations of the water table to maximize crop yields.

At Clemson University, Warner (1972) developed a computerized management model, using calculated soil moisture content and forecast probability for rainfall as a tool for making daily decisions for controlling the water table.

Follett et al. (1974) reported that for the irrigation area of North Dakota, corn, sugarbeet, and alfalfa produced maximum yields on a sandy soil with a shallow water table (less than 1 m deep). Neither of the crops responded to irrigation in the test over the shallow water table.

In a field trial on low water-holding capacity sandy soils, Doty et al. (1975) showed a nonlinear relationship for the number of days the water table was maintained at less than 107 cm (42 in) from the surface. Corn silage yields were increased by 1.1 t/ha (0.5 ton per acre) for each additional day that the water table was at 107 cm (42 in) or less from the surface. The water table was at less than 107 cm (42 in) from the surface for a range from 29 to 55 days where the yield and water table measurements were made.

Doty and Parsons (1977) found that a water mound built above the natural water table by a positive head on the tile lines was difficult to maintain as the natural water table dropped. However, yields of shelled corn were increased by 0.07 tons/ha (.03 t/a) for each additional day the water table was maintained between 0.7 and 1.0 meters (28 and 39 in) from the soil surface in a sandy clay loam soil.

Skaggs, 1978, provided a model that explains the formulas and physical laws involved in both drainage and subirrigation. This also shows how the CaRD systems function and has good agreement with the actual operation of several systems in North Carolina.

Benz et al. (1978) reported that yields for three crops (corn, sugarbeets, and alfalfa) grown over a shallow water table (1.2-1.8 m deep) were much higher than those for medium (about 1.8-2.4 m deep) and deep (about 2.1-2.7 m deep) water table on a Hecla sandy loam soil in North Dakota. The reported three-year average for applied-water-use efficiencies for corn grown under the shallow water table ranged from a high of 26.7 kg/ha/mm for the nonirrigated treatment to a low of 11.5 kg/ha/mm for the maximum irrigation treatment on which 1.5 times the estimated irrigation requirements were applied each week. Yields of sugarbeet sucrose and alfalfa showed similar results. The addition of only 0.5 percent of the estimated irrigation requirements reduce yields significantly on the shallow water table treatment. This indicates that water supplied to the crop from the water table was ample and additional irrigation was excess.

Doty (1979) concluded that a CaRD system on a sandy clay soil furnished ample water for corn production over a three-year period with the exception of one eight-day period. During those eight days, evapotranspiration was about 1 cm per day. Because the hydraulic conductivity of the soil was only 120 cm/day, water could not be supplied through the soil fast enough to meet evaporative demands.

Recharging Ground Water

Palkovics et al. (1975) showed that the rate of stream flow and the water table level in the soil changed similarly on a forested watershed in central Pennsylvania. Further, Palkovics and Peterson, (1977) calculated stream flow from the decline in water table in the soil. Their "results indicated water yield from the soil aquifer explained stream flow." If the water table level affects the stream flow rate, then there is reason to believe that the water table level in the field can be controlled at the desired depth by controlling the stream flow. In a discussion of groundwater levels based on data from Ahoskie Creek watershed and Creeping Swamp watershed, Winner and Simmons (1977) state, "if the increase in base runoff results from increased groundwater recharge, we would expect a greater range in groundwater-level fluctuation after the channels are deepened, with the greatest change in amplitude occurring near the stream and relative little change in amplitude occurring at the divide." In discussion of the water budget, they state, "because deeper channels result in an increased fluctuation in groundwater levels, with the lowest levels being reached during the summer growing season, it might seem that evapotranspiration losses from the surfician aquifer would be reduced". However, as pointed out, this should be reflected in increase in total runoff; this was not the case on Ahoskie Creek watershed (Knisel et al. 1977), and was not projected for Creeping Swamp watershed (Winner and Simmons, 1977). Water table depths increasing to 5 feet from the surface have been shown to reduce evapotranspiration (Whisler and Brater, 1967). If the water table can be controlled at the proper depth, then the crop can use water from the fringe area to supply water for the evapotranspiration process, Palkovics et al., 1975, and Reicosky et al., 1976.

Weston and Swain (1979) studied the physical possibility of artificially recharging the groundwater system in the South Platte River basin in Colorado. "The analysis indicate that recharge of the alluvial aquifier is physically possible, but some problems associated with high water tables and differences in water quality may be expected." Waterlogging conditions are likely to develop in areas that lie within 1 to 3 km of the river. High concentrations of dissolved solids in the recharge water may deteriorate ground water enough to make it a poor source for domestic and municipal water supplied in some areas.

Present South Carolina System

Mr. Lance Williams, a farmer in Marion County, S. C., is one of the leaders in developing a total water management system. He is controlling an entire stream which in turn controls the water table on his farm. A dug lake is used for storage. All excess water leaves the farm through an 18-inch culvert spillway in the storage reservoir. Mr. Williams uses both subsurface and flood irrigation in his water management system.

On the Spring Island Plantation, off the South Carolina coast near Beaufort, the Soil Conservation Service designed and assisted in the installation of drainage on a 160-ha system consisting of parallel ditches spaced 90 to 150 m apart. Following installation, crops did not grow satisfactorily because of extreme drought. However, after control structures were added and the water table raised to within 1 m of the soil surface, the crops were no longer subject to drought and produced 6.3 t/ha of corn.

Mr. Johnny Brailsford, Brailsford's Nursery, Orangeburg, S.C., grows trees for commercial transplanting. He uses a CaRD system in a dual purpose (1) to supply moisture for faster growth on his trees and (2) to keep the soil moist and conditioned for tree removal. Mr. Brailsford operated his system in the following manner: When the trees needed water, the ditches were filled which allowed the soil to be saturated through the tile lines. When the soil was moist to the surface in the fields, the water level in the ditches was dropped to facilitate drainage. At present, he controls the water table by keeping the water level in the ditches at an almost constant depth.

Mr. Earl Marvin, Wildwood Plant Nursery, Walterboro, S. C., has a multiirrigation system consisting of overhead sprinklers, trickle, and two CaRD systems. One of the CaRD systems is on a slope of about 2 percent. The control ditch is at the top of the slope and the tile lines run from the ditch down slope in the direction of the mean contour. During the extreme drought of 1977, he sustained heavy losses everywhere but in the CaRD fields. Because of labor and time, he was unable to irrigate all the areas covered by the sprinkler and trickle irrigation systems. However, in the field with the CaRD system, very little labor was required which resulted in no loss from drought. In addition, the soil remained in excellent condition for plant removal. He is very pleased with CaRD systems and has replaced the sprinkler and trickle systems in four fields with CaRD systems and is in the process of doing so in his other fields.

Mr. Frank West, of Marion County, S. C., has two CaRD systems. One system uses only the water from natural rainfall, which is stored in the ditches and underground. This 1,000-acre system has produced excellent yields of corn, oats, and soybeans. The water, stored underground, is transferred from the soybean side of the field to the corn side when the corn need water. After the corn is mature, all water is returned to the soybeans through the ditch system. In another 400-acre system, wells are provided and the CaRD system is used to distribute the water from these wells to the entire area.

Presently, Henry Young, of Orangeburg, S. C. has completed about 150 acres of a proposed 1,000-acre CaRD system. The soils in the area range from a Coxville sandy loam to a Raines loamy sand. Mr. Young has a well which produces about 2500 gal/min to supply water for the system. In addition, water can flow by gravity from a large swamp area adjacent to the fields. Eventually, the ditch system will carry water from the well to the entire 1,000 acres by gravity flow.

The 1.7 ha research CaRD system on the new Pee Dee Experiment Station, Florence, SC, has been operated for the past five years. The system was installed in a Goldsboro soil on a site that would not normally be used for controlled and reversible drainage, to study water supplied by a CaRD system in a slowly permeable soil by building a water mound by means of a head on the tile lines. A water mound can be built, but when the natural water table in the surrounding area drops, so does the mounded water table. Research is needed to study the control of the water table over a larger area than that with which we are presently involved.

A Look at the Future

The future of agricultural progress in the Southern Coastal Plain, an area with abundant water supplies and radiant energy, lies in developing more efficient systems for managing available water resources. The development of new and/or improvement of current soil and water management systems to compensate for the natural water deficiencies and excesses which adversely affect plant growth and hinder farming operations is a major need for this area. Totally new concepts and investigative approaches must be developed. Much of the drainage and irrigation technology, developed primarily for the midwestern and western U. S., cannot be adapted directly to conditions in the Southern Coastal Plain because of different soil, topography, and climatic factors.

Soil Conservation Service personnel in North and South Carolina, Florida, Georgia, Maryland, Delaware, and Virginia are continually receiving requests for assistance in designing water table management systems.

The impending energy crunch may have a direct bearing on the future development of water management systems. Energy may not be available to pump water from deep aquifers for irrigation or to furnish pressure for sprinkler irrigation systems. Therefore, farmers may have to use a readily available and abundant source of energy -- gravity and slope gradient.

CaRD systems are designed to use gravity as their main force for an energy source. In the future, more and more CaRD systems will be completed.

Inadequate surface-water supplies are becoming a problem. "Analysis show that instream flows generally are considered inadequate in the West and they also indicate that instream flows are of concern in the East." (U. S. Water Resources Council, 1978).

CaRD system will help eliminate these problems. Stream flows will be checked and the water stored underground near the stream channels and used for irrigation and domestic use instead of flowing downstream and wasted into the ocean.

Ground water is being diminished in several areas of the United States. "Diminished artesian pressure, declining spring flow and stream flow, land subsidence, and salt-water intrusion generally indicate that ground water is being withdrawn at a rate greater than an aquifer is being replinished." (U. S. Water Resources Council, 1978) Also, in this report there are concern for our wetlands. "Wetlands provide food and cover for waterfowl, wildlife, and sport and commercial fish. Waterfowl depend on wetlands for breeding and wintering habitat, particularly along migratory routes. Wetlands also can retain flood waters and trap pollutants. Because of the conflicts between the interest to drain land for crops and the need for wetlands for fish and wildlife, planning for drainage should include a thorough evaluation of economic, social, and environmental effects."

The use of CaRD systems on complete drainage districts will increase the amount of groundwater stored and at the same time protect wetlands. Portions of the water stored underground should percolate downward and replenish the underground water supply. Control, with various CaRD systems, can be implemented in such a way that swamplands may be left for wildlife and the surrounding farm land utilized to produce more abundant crops. Proper design of the CaRD system will meet the requirements for a total water management system.

Economics is another factor to consider for a CaRD system. For example, in some of the low-lying areas of the Coastal Plain, drainage is necessary; the seedbed cannot be prepared without drainage. But come July, the soil is so dry that crops cannot grow. A tile system is a must and so is irrigation. Therefore, with a CaRD system, the farmer essentially gets both the irrigation and drainage system for the price of the drainage system.

The drainage channels of the 65,000-acre drainage district on Conetoe Creek (Conetoe, NC) were constructed in 1967. Here, thousands of acres of cropland that once were flooded several times a year are now receiving flood protection and improved drainage. However, to drain parts of the district it was necessary to cut large channels over 3 m deep, Fig. 1. A preliminary study was started by C. W. Doty, SEA, and SCS personnel to determine the water table drawdown at various distances away from the deep and shallow channels. These deep channels draw the water table down about 2 m below the surface, Fig. 1, and affect the water table at least 500 to 700 m from the channel. With shallow channels this effect is not as drastic, Fig. 2. Knisel et al. (1977) reported that the base flow of streams was greater on Ahoskie Creek in N. C. after channelization which means that water is being removed from the fields on each side of the stream. Farmers of the area are reporting an increasing need for irrigation and lowering of some shallow wells near the channels. One farmer reported that yield increased in relation to the distance going away from the drainage channel. This report was from the same field where the water table was measured in Fig. 1, indicating that the closer the water table is to the surface (within limits) the better the yield. Knisel et al. (1977) reported, "groundwater in the Yorktown aquifer was recharged to near capacity each year with the channel system that now exists in Ahoskie Creed watershed. While some water drained from the aquifer during the growing season and maintained beneficial low flow, the acquifer was recharged annually to near capacity during the dormant season." However, it is during the growing season that the farmer is concerned. The Soil Conservation Service and the farmers in the Coastal Plain are concerned that drainage channels are a must, but better water control system during dry times are also needed.

Studies are now being conducted to evaluate present methods for design and operation of water management systems and to develop field-derived criteria to modify these systems for economic efficiencies in water resource projects in the Coastal Plain. CaRD systems on a drainage district basis should have an impact not only on the farm land but should also impact on ecology as well.

SUMMARY

Past research has shown that controlling the water table between 60 and 100 cm depth will provide increased yields and that it is physically possible in the more permeable soils to control the water table to this depth.

CaRD systems now in operation in South Carolina are gaining farmer acceptance. Lending agencies are looking at water table control as a sound investment for the farmer.

Controlled and reversible drainage systems provide a possible means to minimize irrigation water requirements. The soil is an economical storage reservoir for water. However, when the soil reservoir remains full too long, crop suffer from oxygen stress. Computer models at N.C. State and Clemson Universities, and field research at N.C. State, Clemson, and Florence, S.C., and in Florida have shown drainage and subirrigation through the same tile system to be very beneficial for increased crop production. Research has shown that in the low water-holding-capacity soils, crops suffer from drought stress in three to seven days after a saturating rain. In the humid regions, high intensity and extended rainfall periods make the installation of drainage systems necessary. An economical approach to amelioration of short-term droughts is to irrigate through the existing drainage systems.

Water level control is applicable to 1.5 million acres of land in South Carolina alone and can be utilized in the Coastal Plain states ranging from Delaware to Texas. It can be practical on small plots or on large fields.

Research is needed on a complete watershed without any island effect to determine if a CaRD system will affect yields at various distances from the channel and what effect it will have on water management systems, water quality, ground water recharge, yield, and the timely conduct of farming operation.

In water management planning, we sometimes like to "have our cake and eat it, too." This may be possible in the future provided we "play our CaRDS right."

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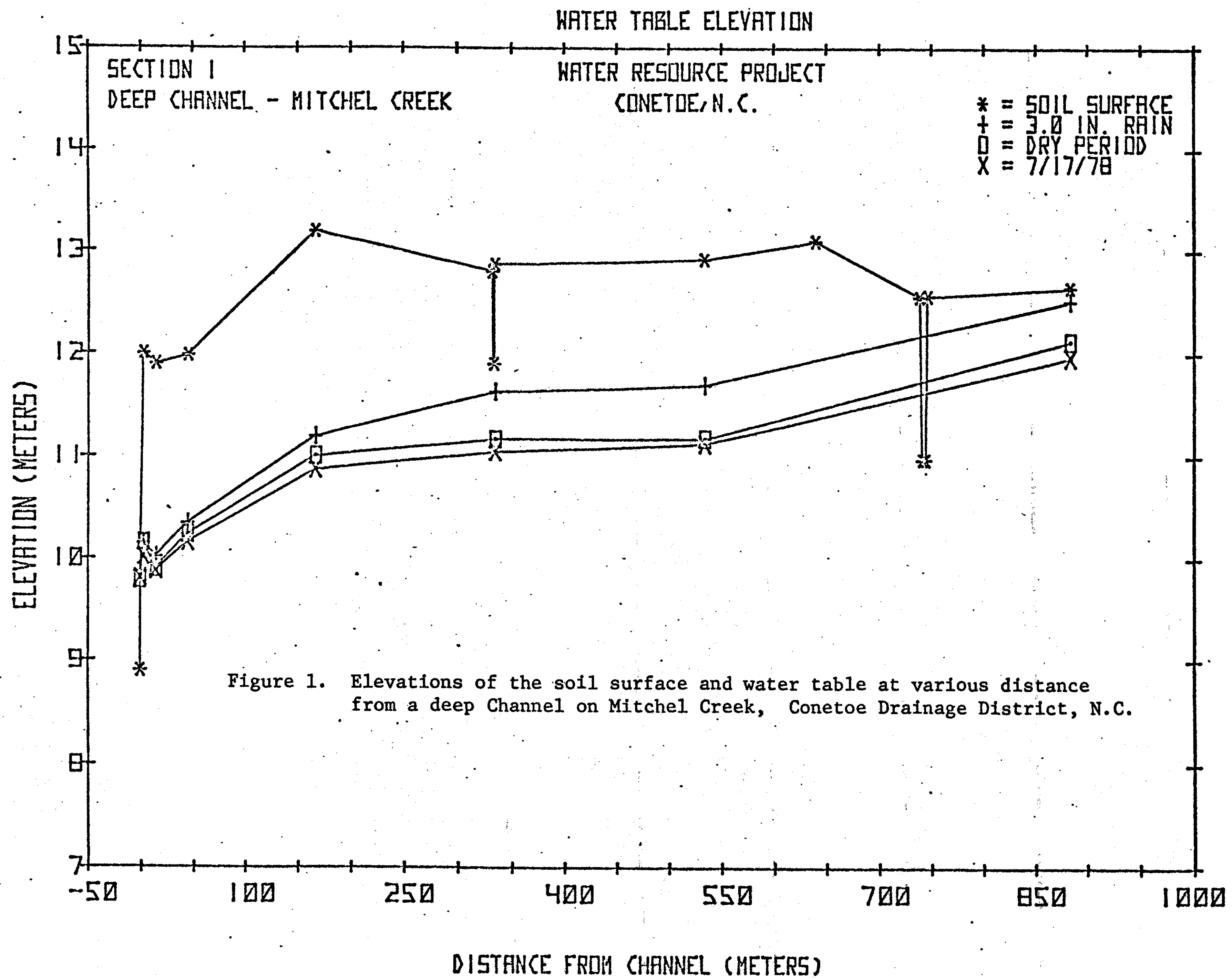

Figure 1. Elevations of the soil surface and water table at various distance from a deep Channel on Mitchel Creek, Conetoe Drainage District, N.C.

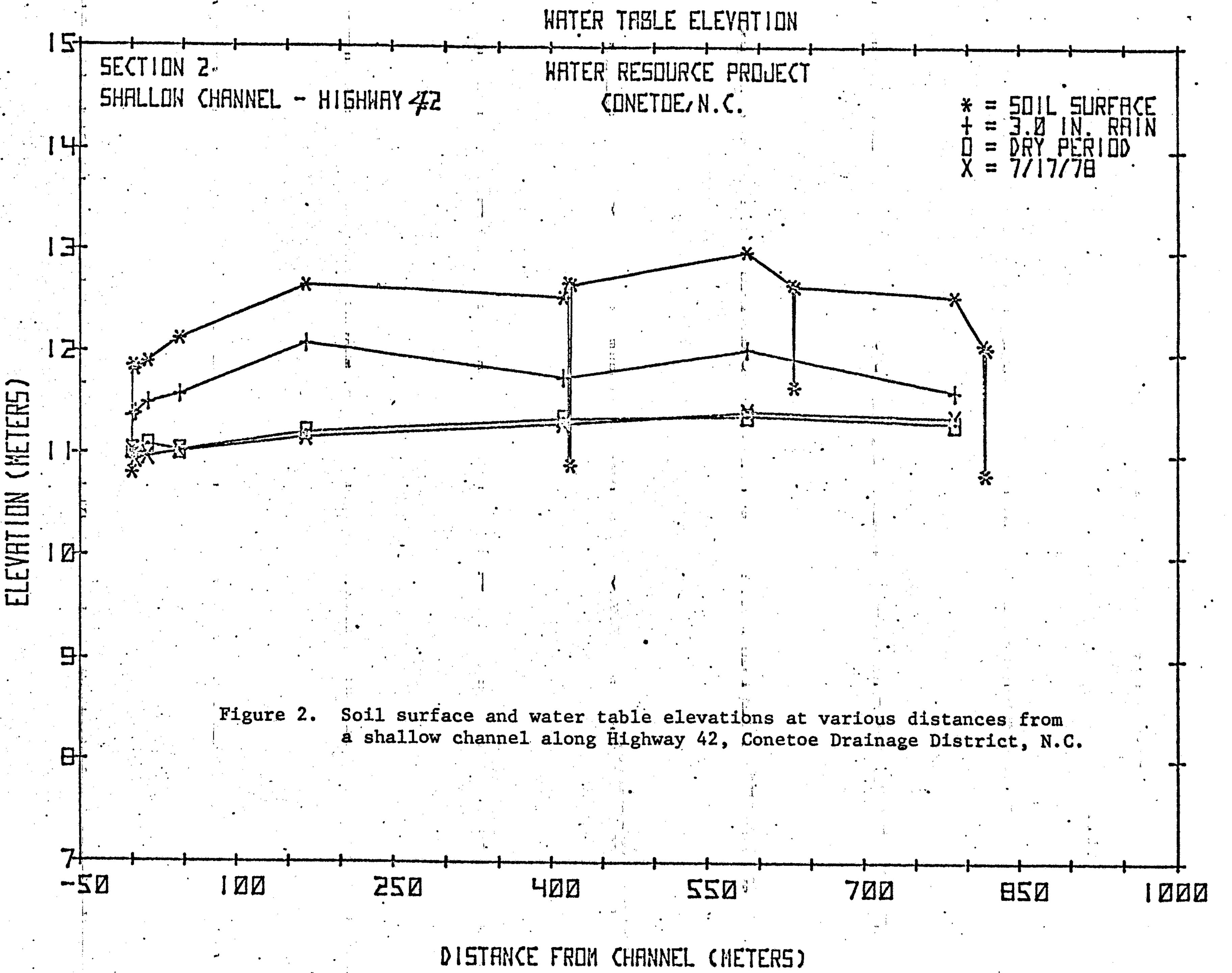

Figure 2. Soil surface and water table elevations at various distances from a shallow channel along Highway 42, Conetoe Drainage District, N.C.